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During 1993, a series of experiments were performed under the Advanced Research Projects Agency (ARPA) sponsorship using the SRI Ultra-Wide Band UHF Synthetic Aperture Radar (SAR). These experiments were performed over a variety of clutter backgrounds to assess the foliage penetration capability of the technology and to investigate target detection in clutter. Experiments were conducted observing tropical rain forest backgrounds in Panama, several different desert backgrounds in the Yuma vicinity, and the mid-latitude temperate forest of Maine. SAR images were formed from the raw data using Differential GPS to aid in the focusing. The three locations represent different levels of foliage cover, ranging from the sparsely vegetated desert sites to the triple canopied rain forest. The characteristics of each site are discussed first through a presentation of photography and SAR imagery. The clutter characteristics are studied through a comparison of the cumulative distributions, which are plotted using a variety of conventions (e.g., log-normal, normal, Weibull). For each case, at least one reference target is included in the test scene. The signal of that target as processed by a common algorithm will be compared to the processed clutter distribution.

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Comparisons of target detection in clutter using data from the 1993 FOPEN experiments

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ABSTRACT

During 1993, a series of experiments were performed under the Advanced Research Projects Agency (ARPA) sponsorship using the SRI Ultra-Wide Band UHF Synthetic Aperture Radar (SAR). These experiments were performed over a variety of clutter backgrounds to assess the foliage penetration capability of the technology and to investigate target detection in clutter. Experiments were conducted observing tropical rain forest backgrounds in Panama, several different desert backgrounds in the Yuma vicinity, and the mid-latitude temperate forest of Maine. SAR images were formed from the raw data using Differential GPS to aid in the focusing. The three locations represent different levels of foliage cover, ranging from the sparsely vegetated desert sites to the triple canopied rain forest. The characteristics of each site are discussed first through a presentation of photography and SAR imagery. The clutter characteristics are studied through a comparison of the cumulative distributions, which are plotted using a variety of conventions (e.g. log-normal, normal, Weibull). For each case, at least one reference target is included in the test scene. The signal of that target as processed by a common algorithm will be compared to the processed clutter distribution.

1.0 INTRODUCTION

The statistics of radar clutter have been long considered as an important factor in the design of automatic target detection algorithms. In an early article Finn[1] investigated a processing approach which maintained a constant false alarm rate (CFAR) in clutter. The clutter considered was Rayleigh distributed and the detection algorithm estimated the clutter from the cells locally surrounding the candidate target. The detection threshold was then set at some constant multiple of the mean local clutter, which assured a constant level of false alarms. Later, constant false alarm rate detection was addressed by Goldstein[2] for clutter modeled both as log-normal and Weibull distributions. A test based upon two parameters was shown to result in a constant false alarm rate.

In this paper the clutter statistics of SAR data taken by an Ultra-Wide Band UHF sensor are presented. Clutter from an UWB UHF sensor has different properties from narrow band higher frequency SAR. High frequency SAR is dominated by speckle, which is a result of the statistical nature of the radar scatterers. UWB UHF SAR clutter is essentially speckle-free. UHF has greater foliage penetration capability than high frequency. Thus, it is important to determine the statistics of the clutter background for UWB UHF of SAR to aid in the design of algorithms to detect targets under foliage.

The data analyzed in this paper is from a series of flights sponsored by ARPA in 1993[3] over a variety of different clutter terrains. The representative different clutters range from dense tropical rain forests to desert dunes. Data in temperate forests and partially vegetated deserts are also included in this analysis. Samples from this large data base were chosen and analyzed for a comparison of the best fits to various statistical distributions. Fits to normal, log-normal and Weibull distributions are presented in this paper.

In a final section, a common detection algorithm using a two parameter constant false alarm rate (CFAR) technique is applied to each of the clutter data sets. In three of the data sets a target was placed in the flight path and the target detection level is presented. While the target cannot be compared from case to case because different type targets were used and the circumstances of the detection (target orientation, etc.) were also different, the results are illustrative of the detection process against the clutter.

2.0 EXPERIMENTS

ARPA has been interested through the War Breaker program in foliage penetration (FOPEN) SAR. During 1993, ARPA sponsored a series of measurements in different environments to determine the ability of low frequency SAR to detect targets under foliage. Under ARPA sponsorship and under the direction of MIT Lincoln Laboratories, several different experiments and sensor platforms were used to investigate FOPEN phenomenology. Earlier tests were also conducted in July 1990 by MIT Lincoln Labs in Portage, Maine using the NASA JPL AIRSAR Sensor. This sensor had a narrow band UHF SAR which was used principally for phenomenology measurements of foliage penetration. These results[4] in Portage, Maine showed the basic feasibility of foliage penetration and the anticipated level of attenuation.

Also under ARPA sponsorship and under Lincoln Laboratory's direction, the SRI International Ultra-Wide Band UHF sensor was deployed for a series of experiments starting in 1992. The SRI SAR (called FOLPEN SAR) is a single frequency HH polarization impulse radar operating on a small aircraft at low altitude. For most of the experiments, and for the cases discussed here, a 200-400 MHz band was used. The SAR resolution is under one meter and data is taken over depression angles ranging from 30 to 60 degrees.

The data taken by the SRI Ultra-Wide Band SAR is formed into images using a backwards projection technique. For this paper, images were formed either by Lincoln Labs (the Panama and Maine images) or by Technical Research Associates using the Lincoln Laboratory software. The data sets presented here were all taken with coincident differential GPS. Thus the images were formed using a continually updated estimate of the aircraft velocity. This formation process was iterative because of a requirement to synchronize the time clocks between the GPS and the radar sensor. In each case, the radar is optimally focused using a corner reflector in the field of view. Once a well focused image is formed on the corner reflector, a full processed image is made.

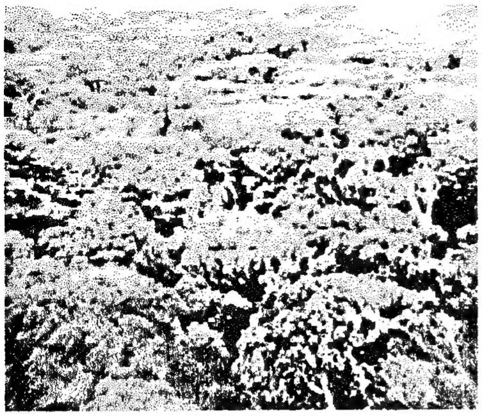
2.1 Panama Experiment

An experiment was performed at Fort Sherman in the vicinity of the Panama Canal in May 1993 for the purpose of gathering backscatter and attenuation measurements for tropical rain forests. In addition, SAR focusing through a dense tropical rain forest and the ability to detect vehicles under foliage was also explored. The forest in the vicinity of Fort Sherman is a dense triple canopy tropical rain forest. The combination of the forest density and its high water content represents an extreme case for foliage penetration. Data was taken by the SRI radar in May 1993 from an altitude of 1000m. Much of this data was supported by differential GPS. A visible light photograph of the forest canopy along with a ground photograph is shown in Figure 1.

The SAR image was prepared by Lincoln Laboratories using corner reflectors in an unforested area for focusing. A 400 x 1600 portion of the larger formed image was chosen since the 400 pixels in range lay within the center of the SRI antenna beam and thus had maximum dynamic range. It also represented a nearly uniform sample of the tropical rain forest. An image of this SAR data is shown in Figure 2. Note that the clutter shows both canopy backscatter and hard tree returns.

2.2 Yuma Experiments

Another experiment was performed in the Yuma, Arizona area in June 1993 with the SRI sensor at three separate sites. The principal purpose of the Yuma experiments was to investigate the detection of buried targets with the SRI sensor and other radar sensors. A secondary objective was to gather clutter data on the desert environment. Two of the sites were used for the clutter sample. The first site was in the Lechuguilla Desert southeast of Yuma. This desert consisted of a series of washes and small bushes and Segura cacti. A clutter experiment was set up viewing one of the washes. The wash was of interest because it is not only an area with higher levels of vegetation clutter due to seasonal flooding but also an area with clutter caused by the water cut wash edges. An aerial photograph of the wash site is shown in Figure 3. The small dark objects within the image are palo verde and mesquite trees. The wash structure can also be seen in this aerial photograph. A ground level photograph of the wash site used for a target deployment is also shown in Figure 3. The target (a five ton truck) was placed behind the small tree such that the radar energy had to penetrate the small tree. A 400 x 1600 SAR image, formed by Technical Research Associates, using the Lincoln Labs image formation software, can be seen in Figure 4. To focus this image, two eight foot corner reflectors were used to optimize the local focus. For statistical processing, the areas around the corner reflectors and the truck target were



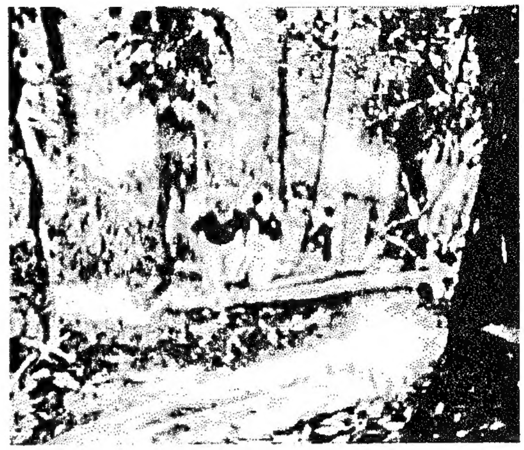


Figure 1. Panama Site Photographs. Aerial Photo on left shows an oblique view of the Rain Forest Canopy. Ground level Photo on right shows ground truth team amidst foliage.

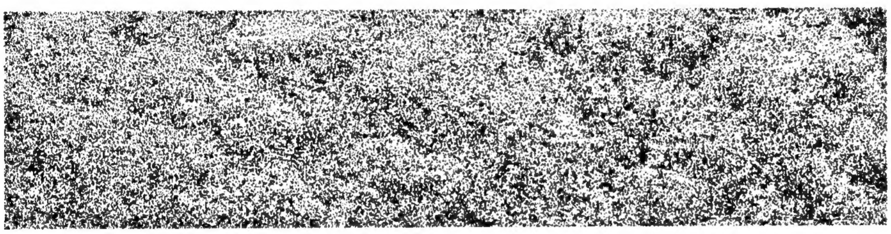


Figure 2. SAR Image of Panama Rain Forest.

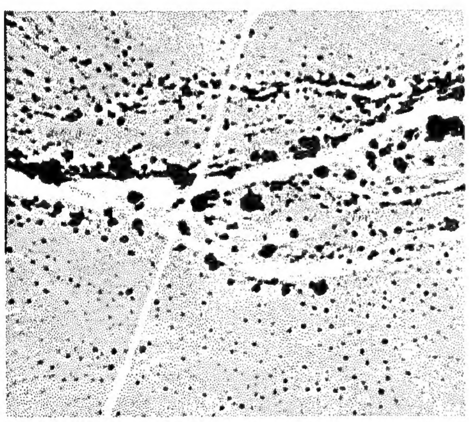


Figure 3. Wash Site Photographs. Aerial Photo is shown on left. Target deployment area is to the left of road. Ground level photo of target deployment area is shown on right.

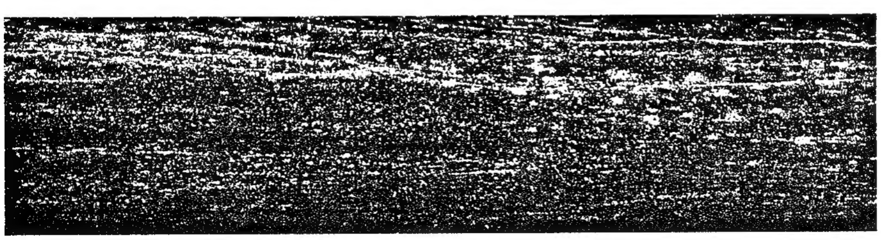


Figure 4. SAR Image of Wash Area.

excluded from the statistical calculation. Note that the clutter consists of linear edges (traceable to the wash edges) along with some isolated clutter returns (probably trees).

A second clutter sample site was in California west of the city of Yuma and was located on sand dunes in the vicinity of the Salton Sea. These sand dunes consisted of undulating dunes with local variations of two to four meters. Scattered within the dunes were small trees. At the point where the dunes transition to the desert (the dune front) there was a concentration of vegetation. The transition from the dune to the general desert terrain at the dune front can be easily seen in Figure 5 (an aerial photograph of the dune front area). Ground level photographs of the dune front area are also shown in Figure 5. In this case the target (a five ton truck) was located in the dune front region. SAR data was collected parallel to the dune front.

An image formed by Technical Research Associates using the Lincoln Lab's image formation software is shown in Figure 6. This image was formed along the dune front where the major clutter source is the small trees. Again this is a 400 by 1600 pixel image in the sweet spot of the SAR image. The dunes did not prove to be a clutter source.

2.3 Maine Experiment

An experiment using the SRI radar was also performed in Maine in late June 1993. The Portage Lake site was chosen since it had been used for earlier experiments with the JPL AIRSAR and the SRI radar. This site is in northern Maine and has extensive stands of mixed deciduous/coniferous trees. An aerial photograph of the Portage, Maine site area is shown in Figure 7. In addition, a ground level image taken along a road showing a clearing in the forest is given in Figure 7. This area represented a less stressful case of foliage penetration than the Panama area. More targets were used for this experiment and target detection results from data taken during this Maine experiment are the subject of another paper[5]. A SAR image formed by Lincoln Labs on the Maine forest is shown in Figure 8. This image is a small portion of a much larger image for the statistical analysis study. Again, a 400 x 1600 image at the center of the antennae pattern was chosen for statistical analysis.

3.0 STATISTICAL ANALYSIS

The purpose of the statistical analysis study was to analyze the cumulative distribution function of Ultra-Wide Band UHF SAR data taken at four different locations, each with a different type of clutter. In each case a 400 x 1600 sub-image was chosen from a larger image. This chosen sub-image contained a target and a representative sample of the clutter. To ensure that the sample was representative, three other samples were also chosen at different cross-range positions within the high dynamic range portion of the SAR sensor. Cumulative distribution functions from each of these other clutter samples were then compared. By this means the inter comparison for a given clutter example could be made. In all cases, the cumulative distribution function appeared to be similar for a given site.

The cumulative distribution function (CDF) is calculated on magnitude data (the square root of the square of the real and imaginary portions). A histogram is formed and a CDF formed from the histogram. Excluded from these statistics are the corner reflectors and any targets. For purposes of comparison the CDF's were plotted on logarithmic scales using normalized units. The normalization on the abscissa is the standard deviation of the clutter. Thus the axis represents multiples of standard deviation. For target detection statistics, the false alarm probability is obtained by subtracting the CDF from unity. The comparative false alarm probability plots are given in Figure 9 for the four cases under study.

Following the comparison of the false alarm probability for the four cases, the data in each case was then fit to several distribution functions. These distribution functions were normal, log normal and Weibull. The data was flattened in range to remove the antenna response by calculating the mean squared of each range line in the cross-range direction. A polynomial was fit to the root mean squared as a function of range. The data was then flattened in range by multiplying the range lines by the inverse of the polynomial. Thus, each range line was scaled by a constant equal to the inverse of the polynomial for that range line. The statistics were calculated on two scales: the full image (400 x 1600) and a smaller sub-image (400 x 50). The second set of statistics may be more meaningful for locally adaptive target detection algorithms since the algorithms operate locally.

In each of the cases, the actual distribution was compared to the assumed distribution using a Kolmogorov - Smirnov (k-s) test. The k-s statistic was taken as a measure of the goodness of fit. Smaller values of the k-s statistic indicate a better fit. A graphical comparison was also performed by plotting the functions with the appropriate axes. Normal probability plotting attempts to plot the CDF to analyze the fit to a normal distribution. There is commercially available probability paper although computer

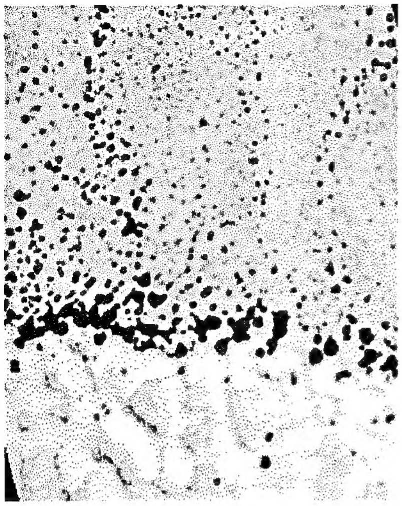


Figure 5. Photographs of Dune Site. Aerial Photo on left shows the dune area on the bottom. Ground level photo shows target location (stake) near a tree at the dune front.

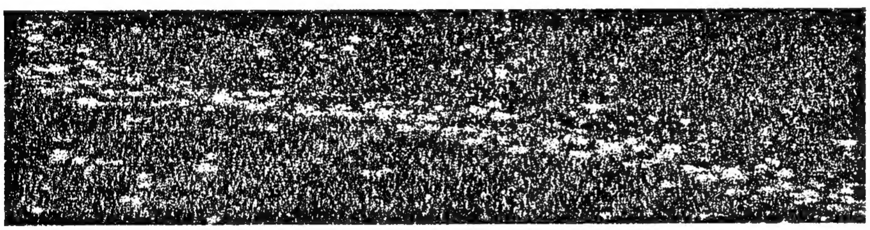


Figure 6. SAR image of Dune site. Corner Reflectors are brightest points in image.

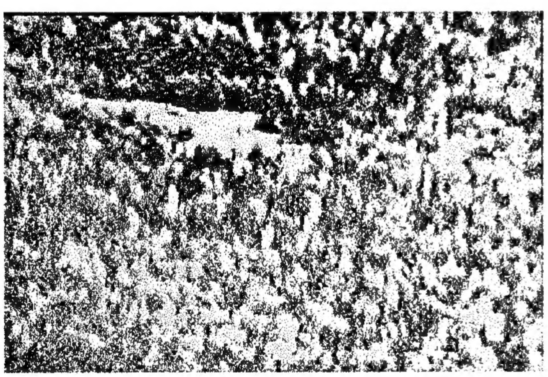


Figure 7. Photographs of the Maine Site. Aerial Photo (oblique view) is shown on left and ground level photo is shown on the right.

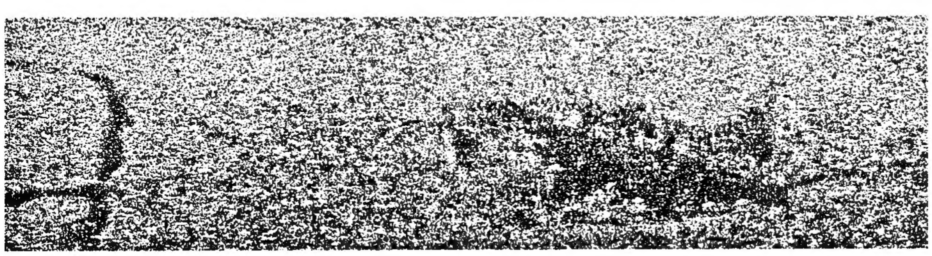


Figure 8. SAR Image of Maine Mixed Forest Site.

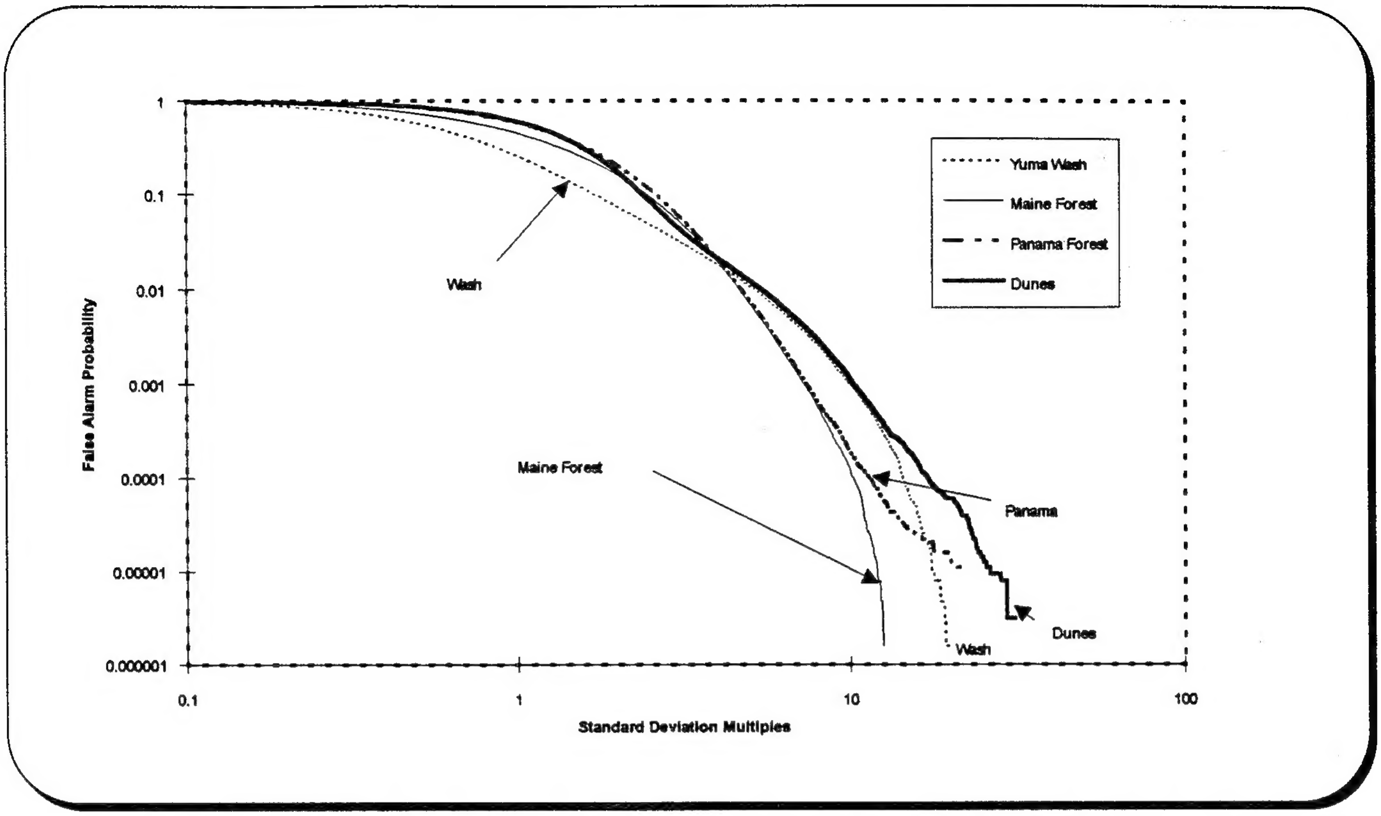


Figure 9. Plot of the False Alarm Probability for the four backgrounds. Plot is logarithmic with the abscissa multiples of the standard deviation for each case. Statistics calculated over the full 400 by 1600 image.

algorithms exist to accomplish this. The log-normal distribution is similar to the normal distribution. The vertical axis is the same but the horizontal axis (corresponding to signal strength) is plotted with a logarithmic scale. Comparison to a two parameter Weibull distribution is accomplished by plotting:

$$z = \ln(-\ln(1 - Fn(I))) \tag{1}$$

as the ordinate against ln (I) as the abscissa.

The k-s tests are summarized for the four scenes and fits to three distributions in Tables 1 and 2. The results in Table 1 are for the full 400 x 1600 image in each case. The log-normal distribution is a best fit for both the Yuma Wash and Maine scenes, whereas the Weibull and log-normal are equally good fits for the Panama and Dunes cases. The results in Table 2 are similar except that Maine scene is equally well fit by the Weibull and log-normal.

Plots of the best fit cases for each scene for the smaller sub-images are given in Figures 10-13. The plots show the assumed distribution as a line and the actual distribution as a curve.

Table 1. Statistical Summary - Full 400 x 1600 Images.

	Normal	Log-Normal	Weibull
Panama	0.093	0.029	0.031
Yuma Wash	0.289	0.044	0.074
Dunes	0.15	0.056	0.055
Maine	0.129	0.012	0.035

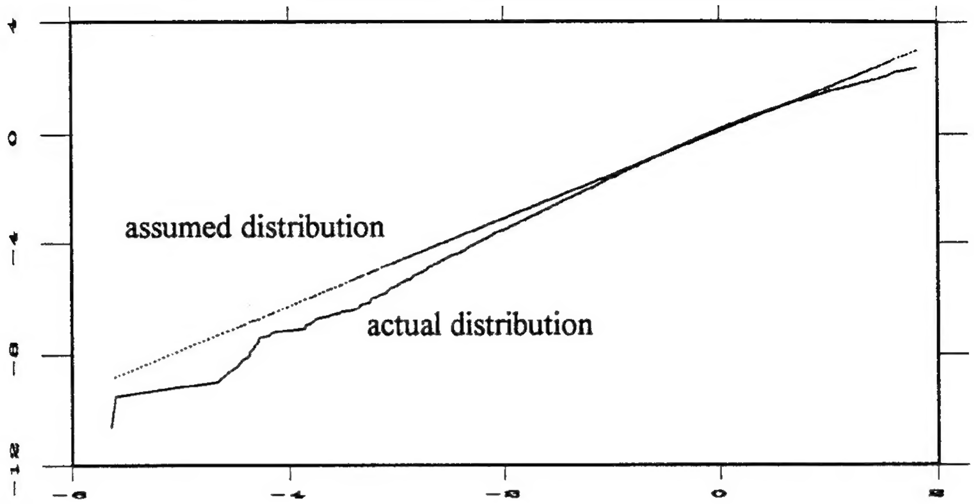


Figure 10. Plot of Fit to Weibull Distribution for Panama Data. Perfect fit is plotted as a straight line on this plot. Axes are scaled to fit distribution.

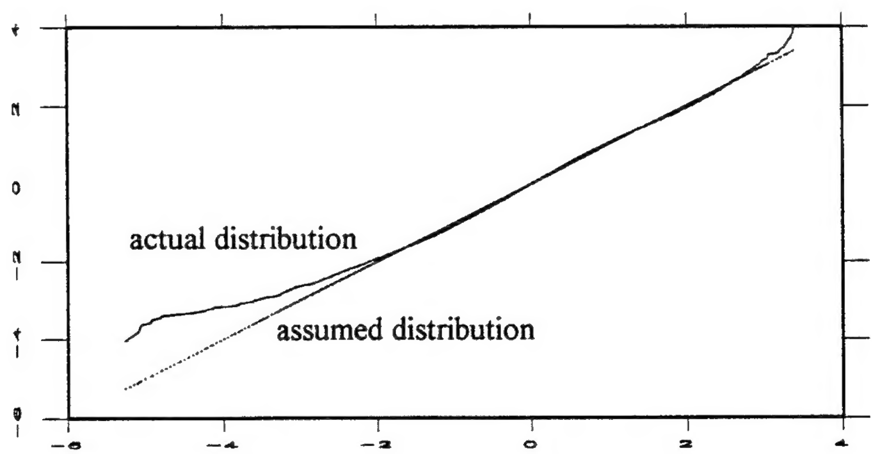


Figure 11. Plot of Fit to Log-Normal Distribution for Yuma Wash Data. Perfect fit is plotted as a straight line .

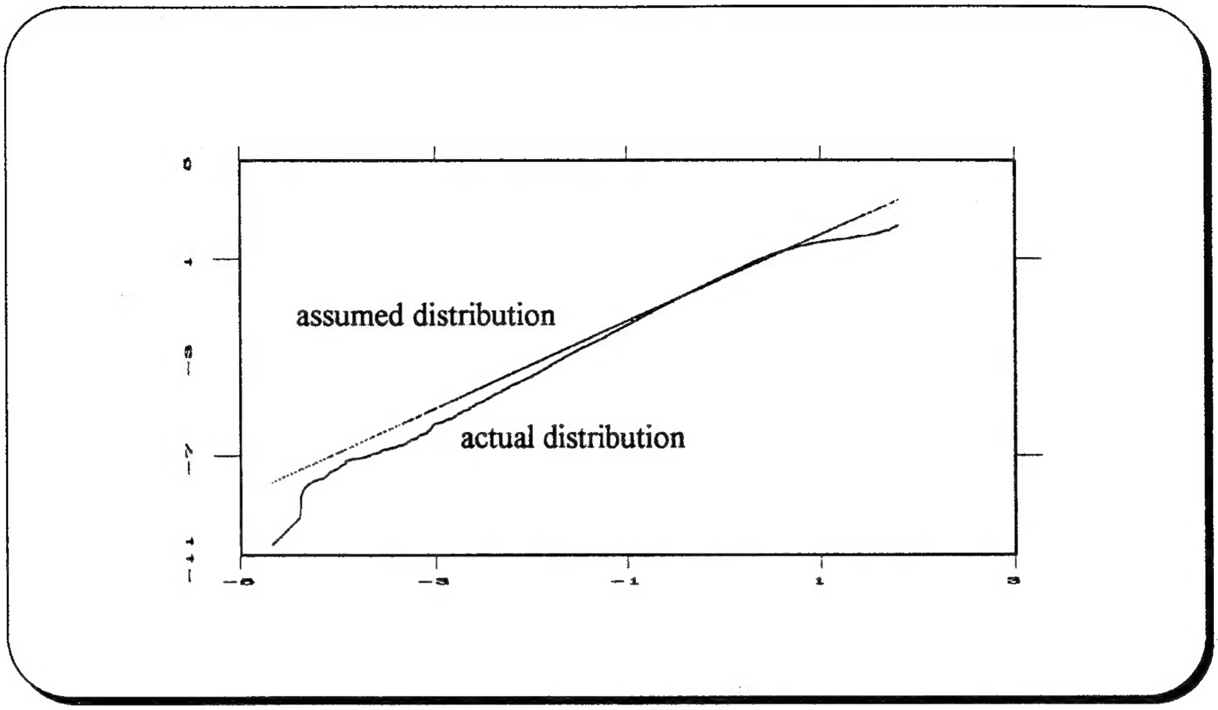


Figure 12. Plot of Fit to Weibull Distribution for Dunes Data. Perfect fit is plotted as a straight line on this plot.

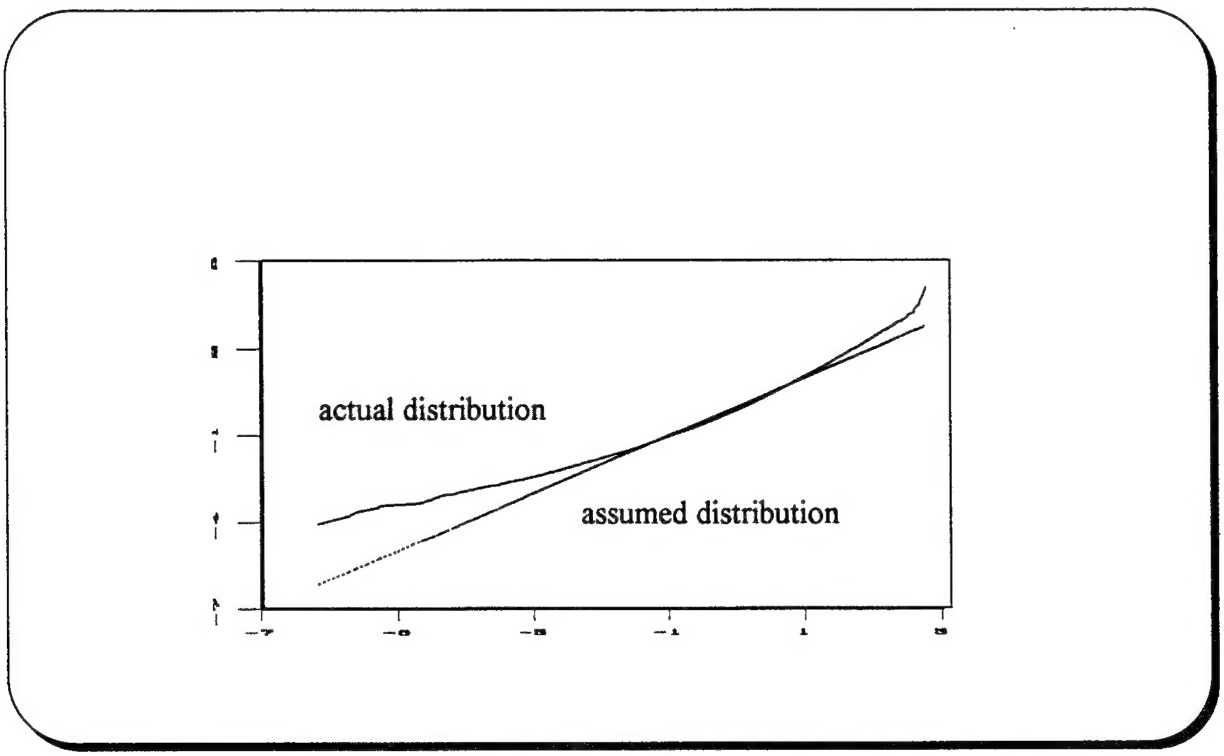


Figure 13. Plot of Fit to Log-Normal Distribution for Maine Data. Perfect fit is plotted as a straight line on this plot.

Table 2. Statistical Summary - Small 400 x 50 Images.

	Normal	Log-Normal	Weibull
Panama	0.079	0.023	0.021
Yuma Wash	0.142	0.03	0.051
Dunes	0.091	0.04	0.034
Maine	0.092	0.03	0.033

4.0 ALGORITHM COMPARISONS

For purposes of comparison a common algorithm was run against each of the four clutter types. In all cases but the Panama clutter case, a target was present in the data. For each case, however, both the target and circumstances of target deployment were different. Thus, no conclusions can be made as to the comparative detection performance of the algorithm in different types of clutter.

The algorithm chosen for tests was the two parameter CFAR algorithm. A CFAR algorithm is generally a processing technique developed to control the rate of false alarms due to changes in background clutter. Initial studies concentrated on a single parameter CFAR technique which worked in Rayleigh clutter. Statistical analysis on high frequency radar data have shown that Rayleigh distributions are poor distributions for describing radar clutter. This same data suggested that log-normal distributions could be an appropriate model of clutter especially when the clutter arises from single scattering elements. Log-normal clutter is different from Rayleigh cluttering in that it has long tails on the distribution and thus for the detection of targets is a much more several clutter environment since targets are normally detected against the tails of distribution. The studies in the last section has shown that the log-normal distribution is also a candidate model distribution for this low frequency Ultra-Wide Band data. The Weibull family of distributions is also a two parameter family and proved to be a good fit for two of the clutter backgrounds.

The two parameter CFAR algorithm is simply described in terms of several equations. The algorithm examines a test cell given by:

$$y = 10\log_{10}|I|^2 \tag{2}$$

where I is the magnitude of the radar return. The following statistic is calculated on the data:

$$z = \frac{y-\mu}{\sigma} \tag{3}$$

In the above equations μ and σ are the mean and standard deviation estimated on a gate surrounding the clutter. Both are calculated on the logarithm of the magnitude. This is graphically shown in Figure 14. The mean and standard deviation are calculated over the small "picture frame" located x pixels from the target. The space between the test cell and the picture frame allows the clutter estimation to be made away from the target to avoid including the target energy in the calculation. The test statistic, z, is then compared with a threshold to determine if a target is present or not. Setting this threshold determines the false alarm probability which is then independent of the mean and standard deviation. If the target exceeds this threshold, the target is declared to be present, if the target does not exceed this threshold it is declared to be not present.

This algorithm was applied to the data sets discussed in the previous section. Rather than setting a threshold, a new image data set was formed by this process. This image data set is an image of the z test distribution discussed above. A cumulative distribution function can be formed on this z statistic image. This distribution then shows the false alarm rate of the algorithm as a function of the threshold. Curves showing this false alarm statistic for the four different images discussed above are given in Figure 15. For the cases where a target was present, the location of the target on that distribution is given.

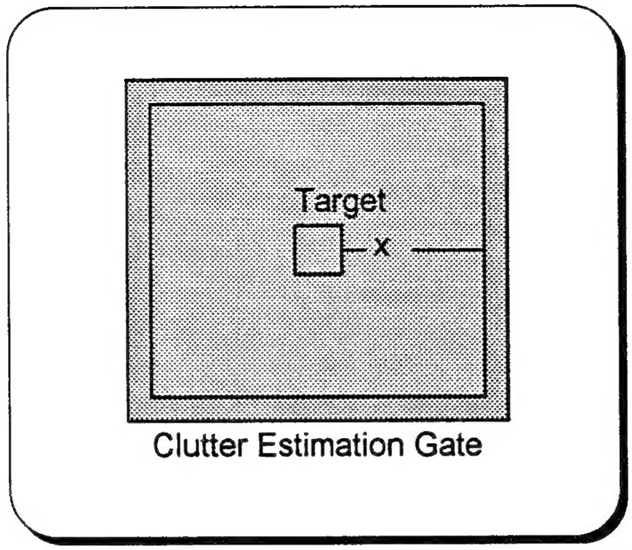


Figure 14. Two Parameter CFAR Algorithm

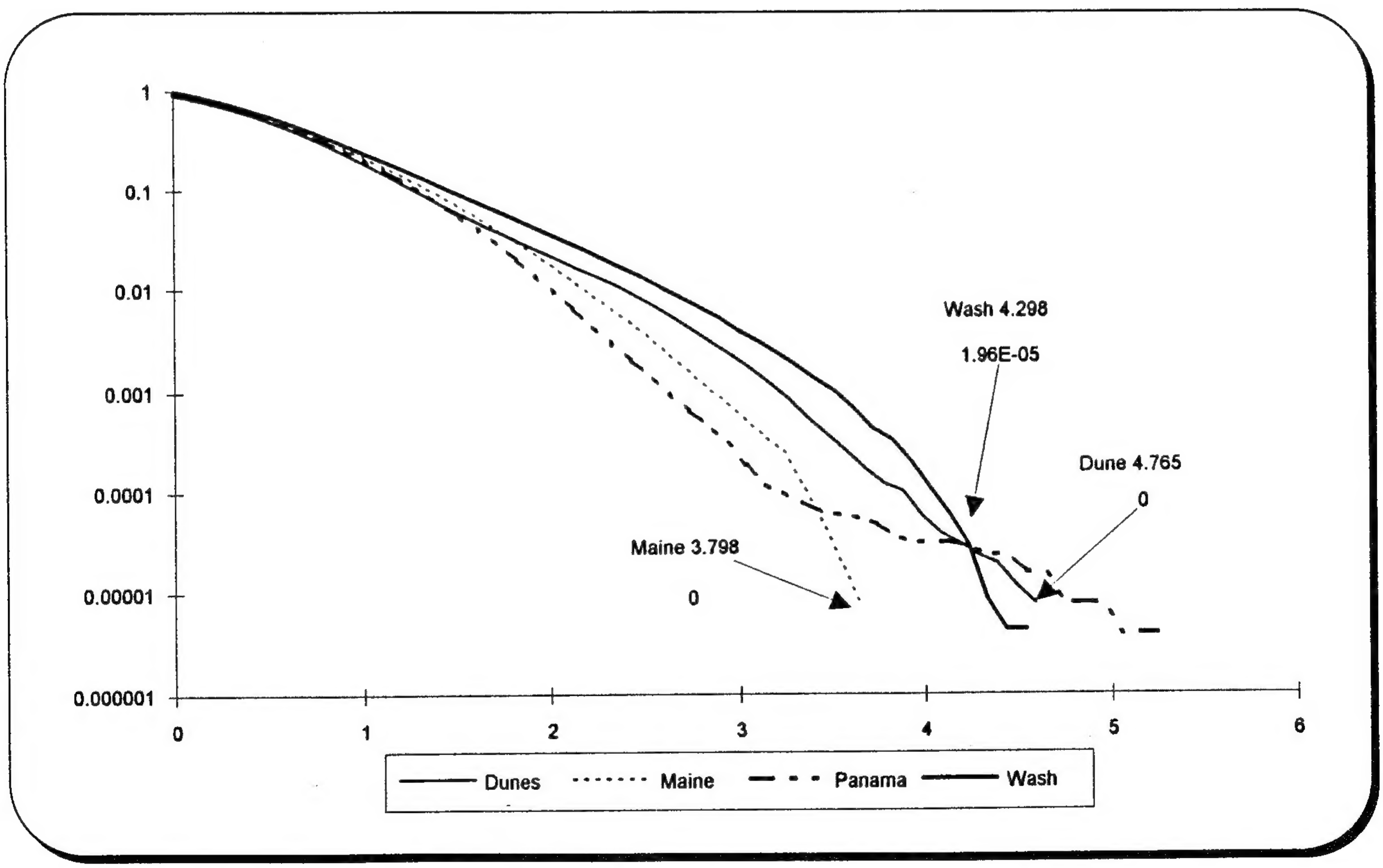


Figure 15. CFAR Algorithm False Alarm Probability for the Four Cases

5.0 CONCLUSIONS

In this paper the clutter statistics of four very different scene types are discussed. In general, for large images, the log-normal distribution is a better fit than the Weibull or normal distributions. For smaller images, the Weibull distribution is also a good fit and the normal distribution fit shows improvement. The two parameter CFAR algorithm had been shown previously by Goldstein to work in the presence of Weibull and log-normal clutter.

6.0 ACKNOWLEDGMENTS

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